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Assessment of Absolute Partial Discharge Intensity from a Free-space Radiometric Measurement

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Abstract— Partial discharge (PD) is measured simultaneously using free-space radiometric (FSR) and a galvanic contact measurement technique based on the IEC 60270 standard. The PD source is an emulator of the floating-electrode type. The radiated signal is captured using a biconical antenna. A method of estimating absolute partial discharge (PD) activity level from a radiometric measurement by relating effective radiated power to PD intensity using a PD calibration device is presented.

Keywords— Partial discharge; free space radiometric measurement; galvanic contact measurement; PD calibration.

I. INTRODUCTION

Measurement of partial discharge (PD) is an important tool in the monitoring of insulation integrity in high voltage (HV) equipment. PD has traditionally been detected by contact (especially IEC 60270) and capacitive/inductive coupling methods. The free-space radiometric (FSR) detection of PD is a relatively new technique. The work reported in this paper addresses the calibration of a floating-electrode PD source required for the development of a PD wireless sensor network (WSN). The calibration of the source suggests the possibility of using free space radiometric measurements to estimate the absolute intensity of PD in HV insulation integrity monitoring applications.

II. APPARATUS

The apparatus used to simultaneously capture FSR and galvanic contact measurements is shown in Figure 1.

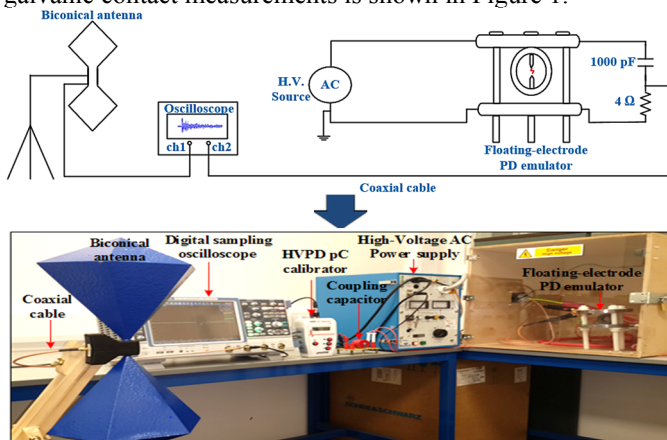


Fig. 1. PD measurement apparatus.

PD is generated by applying an HV sinusoid to the floating-electrode PD emulator. The PD emulator, shown in Figure 2, has 0.60 mm and 6.2 cm gaps on either side of the floating electrode. The voltage rating of the 1000 pF coupling capacitor (shown in Figure 1) used to make the galvanic PD measurements is 40 kV. When the electric field is sufficiently large PD occurs across the smaller of the floating electrode gaps [1, 2].

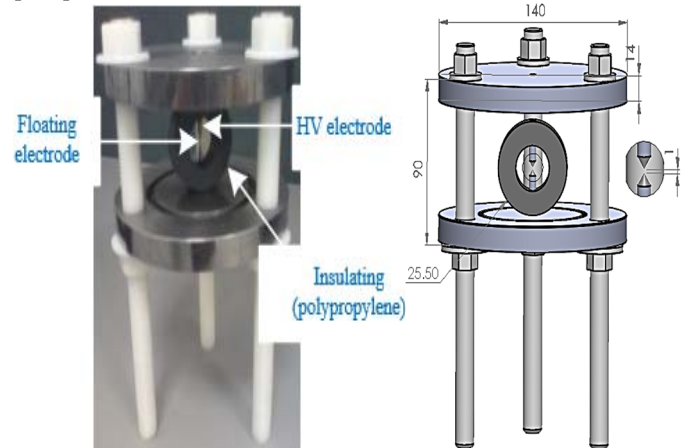


Fig. 2. Floating-electrode PD emulator (dimensions in mm).

The radiometric measurements were made using a biconical antenna connected to a 4 GHz, 20 GSa/s, digital sampling oscilloscope (DSO). The antenna (Figure 3,) was vertically polarised.

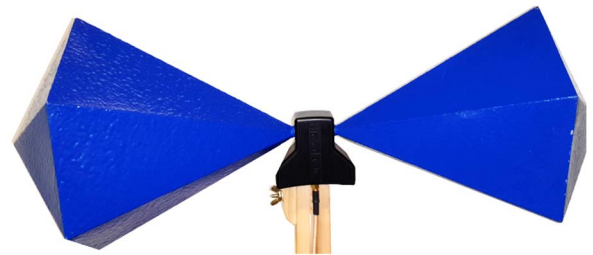


Fig. 3. Biconical antenna used in the FSR measurements.

The frequency range of the antenna is 20 MHz to 1 GHz and its nominal impedance is 50 ohms. The antenna gain at 100 MHz is around -9 dBi and its dimensions are 540 mm×225 mm×225 mm.

A commercial PD calibration device has been used to assess the ERP of the emulator as a function of PD apparent charge. The off-line HVPD pC calibrator is designed to provide a range of current pulses of specified charge from 1 pC up to 100 nC. Figure 4 shows the calibrator [3].

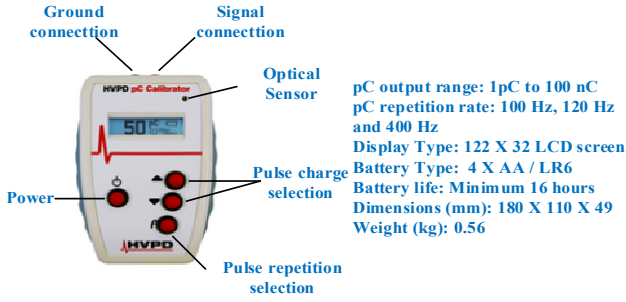


Fig. 4. HVPD pC calibrator with specification [3].

III. PD CALIBRATION

PD intensity, or strength, is specified by the apparent charge transferred during a discharge event. It is typically measured in picocoulombs or nanocoulombs. Strictly, the apparent charge is that charge which, if injected into the terminals of the device under investigation, would result in the same response of the measurement instrument as the response to the PD event [4].

Figure 5 is a plot of the integral of the current pulse resulting from the range of calibration pulses as provided by the calibration device. The pulses were measured using a digital sampling oscilloscope (DSO) with an input impedance of 1 M Ω .

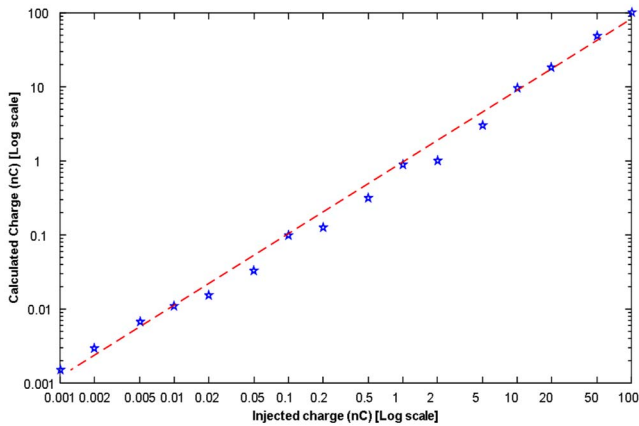


Fig. 5. Integral of measured current pulse (calculated charge) versus calibration device injected charge.

Classical PD measurements, as described in [5], use a galvanic connection to conduct the PD current pulse (or a voltage pulse that is proportional to the current pulse) via a cable to the measurement instrument. If the measurement is sufficiently broadband for the pulse to remain baseband in nature then it is easily, and unambiguously, integrated to find the apparent charge. If the pulse oscillates due to inductance and capacitance of the PD-source/measurement-system combination, however, then the question arises as to how best to assess the apparent charge. The integral from the start of the measured pulse to its first zero crossing has been used as a

measure of apparent charge [6]. This metric has been investigated by comparing it with a range of known charges injected into the emulator using the HVPC calibrator. The measurement circuit is shown in Figure 6. A typical observed waveform is shown in Figure 7.

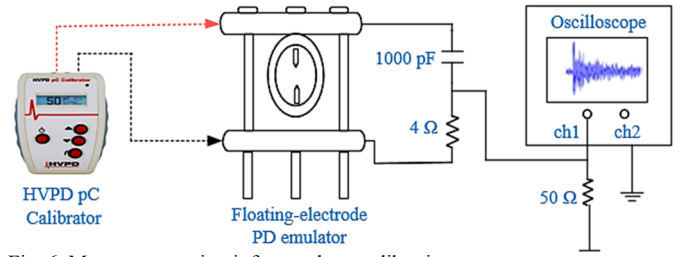


Fig. 6. Measurement circuit for emulator calibration.

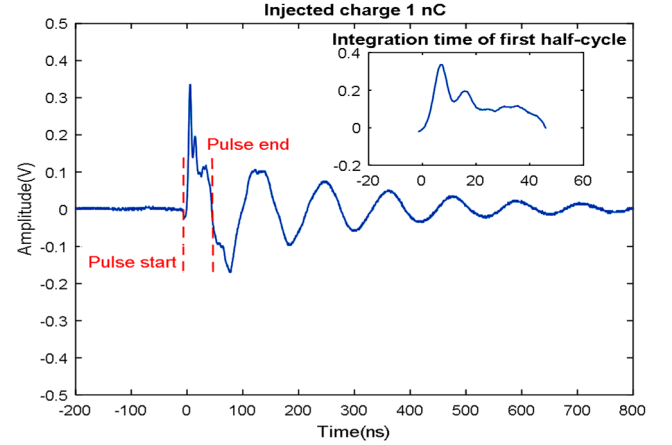


Fig. 7. Measured waveform for an injected charge of 1 nC.

Table I compares injected charge and charge inferred from the integral of the oscillating waveform over the first half cycle. It also shows the peak voltage of the oscillating waveform. The entries from 1 pC to 20 pC were too noisy to make reliable estimates of apparent charge.

Table I. Relationship between injected charge and calculated charge.

| Injected Charge | First half-cycle duration (ns) | Calculated charge | Peak galvanic voltage (V) |
|-----------------|--------------------------------|-------------------|---------------------------|
| 1 pC | - | - | 0.005 |
| 2 pC | - | - | 0.005 |
| 5 pC | - | - | 0.006 |
| 10 pC | - | - | 0.009 |
| 20 pC | - | - | 0.007 |
| 50 pC | 48.0 | 50.8 pC | 0.013 |
| 100 pC | 47.4 | 119 pC | 0.04 |
| 200 pC | 48.4 | 206 pC | 0.03 |
| 500 pC | 45.2 | 544pC | 0.10 |
| 1 nC | 47.6 | 1.5 nC | 0.34 |
| 2 nC | 46.4 | 1.6 nC | 0.21 |
| 5 nC | 44.3 | 5 nC | 0.88 |
| 10 nC | 46.5 | 16 nC | 3.32 |
| 20 nC | 85.5 | 14 nC | 0.96 |
| 50 nC | 84.6 | 35 nC | 2.77 |
| 100 nC | 83.1 | 72 nC | 5.77 |

Figure 8 shows the calculated (first half-cycle) charge against the charge injected by the calibrator.

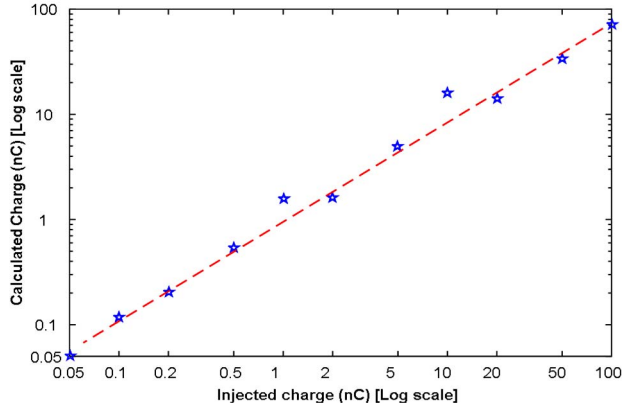


Fig. 8. Calculate charge versus specified charge of charge injection device (setup of Fig. 6).

It is clear from Figure 8 that the first half cycle integral is linearly related to injected charge from the calibrator. By extension we assume that this linear relationship will hold when the charge is injected by a PD event.

It is not obvious that the above can be easily extended to signals radiated by PD events rather than those galvanically conducted to a measurement system. This is, at least in part, because the RF signal at the terminals of a receiving antenna will generally be related to a time-derivative of the PD current pulse rather than a time-integral. Furthermore there are numerous transmission losses that are generally unknown in the case of the radiometrically received PD including the radiation efficiency of the transmitting structure and propagation losses.

Measurements of radiometrically, and galvanically, observed PD signals were undertaken with the measurement system shown in Figure 1. The FSR measurements were made at four distances from the PD source. All the measurements were made using a PD emulator and 50 Hz power supply voltage of 15 kV RMS. Table II shows the received mean peak voltage amplitude, the calculated charge and calculated effective radiated power (ERP) for the FSR measurements. The ERP was calculated assuming free-space propagation and the known antenna factor of the biconical aerial. The range of the antenna from the PD source was varied from 1 m to 4 m in steps of 1 m.

Figure 9 shows the measured FSR peak voltage, the calculated electric field strength and the calculated ERP as a function of measurement range.

In this experiment, the apparent peak ERP varies from 27.1 dBm at a range of 1 m to 24.2 dBm at a range of 4 m. In principle the ERP should be independent of distance. If it were independent of distance then, in a radiometric PD location system such as those described in [7, 8] there seems to be the possibility of inferring an absolute PD intensity (in terms of apparent charge) from a remote radiometric estimate of ERP.

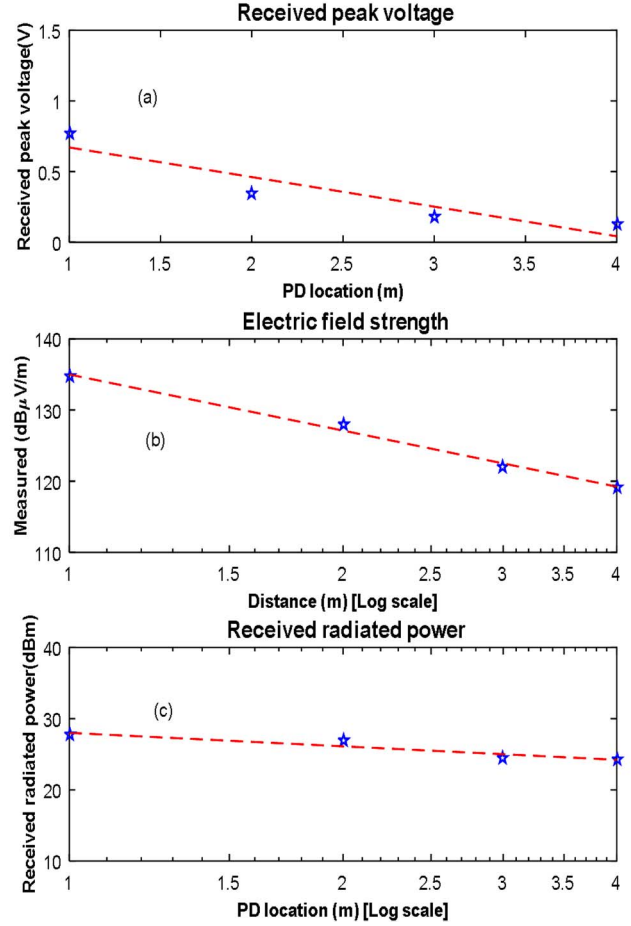


Fig. 9. (a) Received peak voltage, (b) Electric field strength and (c) ERP as a function of PD source – antenna range.

Table II. Concurrent measurements of FSR and galvanic measurements.

| Power supply voltage (kV) | Galvanic measurement | - | Galvanic mean peak voltage (V) | Galvanic mean peak voltage (dBμV) | Galvanic measurement standard deviation (V) | First half-cycle duration (ns) | Calculated charge (nC) |
|---------------------------|----------------------|------------------------------|--------------------------------|-----------------------------------|---|--------------------------------|------------------------|
| 15 | FSR measurement | - | 7.19 | 137.1 | 1.45 | 6.4 | 5.6 |
| | | Antenna - emulator range (m) | FSR mean peak voltage (V) | FSR mean peak voltage (dBμV) | Peak electric field strength (dBμV/m) | Peak ERP (dBm) | Standard deviation (V) |
| | | 1 | 0.77 | 117.7 | 134.7 | 27.7 | 0.30 |
| | | 2 | 0.35 | 110.8 | 127.9 | 26.8 | 0.09 |
| | | 3 | 0.179 | 105.05 | 122.05 | 24.5 | 0.06 |
| | | 4 | 0.129 | 102.2 | 119.2 | 24.2 | 0.03 |

IV. DISCUSSION

The measurement of absolute PD intensity (in pC) from a remote free-space radiometric measurement has traditionally thought to have been impractical. If PD intensity can be reliably related to PD ERP, however, then there is the possibility of inferring PD intensity from a measurement of ERP using a radiometric system that locates the PD source. Several issues remain to be investigated before such an absolute radiometric estimate of PD intensity can be realised. Important of these is the anisotropy of the PD radiation and the error in inferred PD intensity which this introduces in practice. (It is thought that, in practice, the gain of the PD radiating structure will be modest.) Also, inferred ERP in the work above has some modest dependence on range. It is possible this apparent variation is due to the propagation environment in which the measurements were carried out (an indoor laboratory) and the fact that the measurements were not carried out unambiguously in the far field. It is felt that the results reported here are sufficiently encouraging, however, to pursue this work further.

Acknowledgment

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